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A RENAL INDEX FOR MULTIPLE TRAUMA

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Renal function in 751 multiple trauma victims was studied to define a level of function compatible with ultimate survival. The classical definitions of renal failure were ignored. A daily renal index was calculated using commonly measured parameters. The data for 3600 patient days were analyzed on a Univac 1108 computer. Probability of survival was less than 0.1 in patients with a creatinine level greater than 4 mg/100 ml, or a BUN level greater than 80 mg/100 ml, or a renal index greater than 3 on one occasion or greater than 2 on 2 consecutive days. The renal index

(Continued on reverse side)

20. ABSTRACT (Contd)

provided an earlier and more accurate prognosis in a significant number of patients when compared with the other parameters measured. The level of renal function associated with death in the patients studied is considerably lower than currently accepted criteria for initiating hemodialysis. Dialysis to within the levels shown to be compatible with survival offers a method of reducing the high mortality. Clinical application of the renal index as an indication for early hemodialysis in major trauma victims is proposed.

PREFACE

The work described in this report was authorized under Project 3A162110A821, Combat Surgery; Task 1E762708A09022, Automation of Materiel Concepts Design, Engineering and Testing; Chemical/Biological Defense Systems; and AMSAA contract DAA DO5-73-C-[illegible]32. This work was started in September 1973 and completed in May 1974.

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CONTENTS

A RENAL INDEX FOR MULTIPLE TRAUMA

1. INTRODUCTION

1.1 Hemodialysis and renal transplantation have considerably improved the prognosis for patients with chronic renal failure. In contrast, the high mortality rate for patients with acute renal failure following surgery has resisted change (table A-1, appendix*). The failure of therapy in this latter group has been attributed largely to the underlying surgical condition[1,2] and to infection.[3,4]

1.2 The indications for hemodialysis in patients with acute renal failure remain controversial although there is a current trend towards earlier hemodialysis.[2,5-7] Present-day criteria for hemodialysis closely resemble those of 15 years ago, suggesting a stagnation of thought. Posttraumatic renal failure has been recognized as an indication for aggressive management but no clear guidelines have emerged as to when therapy should be initiated.

1.3 The Maryland Institute for Emergency Medicine (MIEM) treats approximately 1000 selected patients each year for major trauma or referred major complications of surgical procedures. Early aggressive "prophylactic" therapy such as mannitol infusions, frusemide, and the careful restoration of normovolemia has resulted in a low overall incidence of anuria. In those patients who do develop significant renal dysfunction, many ultimately succumb to a combination of renal failure, hepatic failure, and sepsis.

1.4 In this study, we ignored traditional definitions of acute renal failure and assessed the renal function of 751 consecutively admitted patients to define a level of renal function with a dismal prognosis. It seems logical that this level of renal function requires hemodialysis to improve the survival rate.

2. METHODOLOGY

2.1 The 751 subjects of this study all had multiple trauma involving two or more body systems or major surgical complications. The parameters for each patient were measured daily and stored in a Univac 1108 computer; for this study, they consisted of the blood urea nitrogen (BUN), the serum creatinine, the hourly urine volume, and the survival or death of the patient. No preconceived level of renal function was defined as "renal failure" or as being compatible with life or death.

2.2 Daily measurements were made of the serum creatinine and the BUN (urease method)[8] on the 8 a.m. blood sample. Each patient's 12-hour urine output was measured and converted to a value (urine vol_N) as shown in table A-2.

2.3 The maximum values of BUN and creatinine and the minimum values of urine output obtained during the patient's hospitalization were correlated with eventual survival or death.

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*All other tables are in the appendix.

2.4 The daily values for these parameters were also used to calculate an index of renal function (RI) using the formula:

$$RI = 1/3\,(Creat_N + BUN_N + \text{Urine vol}_N)$$

where

$$Creat_N = \frac{\text{(Measured creatinine)} - \text{(Mean serum creatinine level of survivors)}}{\text{One standard deviation of serum creatinine level of survivors}}$$

and where

$$BUN_N = \frac{\text{(Measured BUN)} - \text{(Mean BUN of survivors)}}{\text{One standard deviation of BUN of survivors}}$$

2.5 The renal index was computed for each patient day and the highest value was correlated with patient survival. Based upon individual parameters and a combination of all three, the level of renal function was related to the probability of survival, and a level was defined at which survival became unlikely. This was regarded as the critical level of renal function. A further analysis was performed to identify the parameter which provided the earliest warning of this "critical" state and the BUN, creatinine, urine volume, and renal index were compared to determine which reached the critical level first and most consistently.

3. RESULTS

3.1 Seven hundred and fifty-one patients with levels of renal function varying from normal to complete anuria as a result of acute renal failure were studied for an average of 5 days, with a range of 0 to 30 days and a total of 3,600 patient days. Those patients who died (age 38 ± 21 years) were separated from the survivors (age 30 ± 17 years). According to the formula outlined:

$$Creatinine_N = \frac{\text{Measured serum creatinine level} - 0.89\text{ mg \%}}{0.47\text{ mg \%}}$$

where 0.89 is the mean serum creatinine level derived from the estimations on 551 surviving patients on the day of discharge and 0.47 is the standard deviation.

$$BUN_N = \frac{\text{Measured BUN} - 14.3\text{ mg \%}}{11.0\text{ mg \%}}$$

where 14.3 is the mean BUN derived from estimations on 551 surviving patients on the day of discharge and 11.0 is the standard deviation.

3.2 Table A-3 shows the relationship of the individual parameters and the renal index to survival or death of the patient. The probabilities of survival of these groups are shown in table A-4. Creatinine levels greater than 4.0 mg/100 ml, a BUN over 80 mg/100 ml, a renal index of 3 on one occasion or a renal index of 2 on two or more days were all rare occurrences in the survivors. Those patients who did have one of the criteria just mentioned were further analyzed to identify that parameter which first reached the "critical level" (table A-5).

3.3 In the majority of cases, the most sensitive parameter was a renal index of 3. The renal index is related to the patient's ultimate prognosis in table A-6, demonstrating a 100% mortality increase when the renal index changes from 2 to 3.

4. DISCUSSION

4.1 Although acute renal failure following surgery or trauma is recognized as a grave complication (table A-7), its appearance rarely provokes the urgent therapeutic response required by the trauma surgeon. The therapeutic approach to acute renal failure in major trauma must be clearly delineated from that to chronic renal failure where the traditional approach pertains.

4.2 Multiple major trauma is usually accompanied by hemorrhagic shock, requiring massive blood transfusion which, by necessity, will often include uncrossmatched blood. Crushed muscle, hematoma formation, infection, and jaundice are commonly components of the primary complicating clinical syndrome. Because of aggressive resuscitation, involving massive colloid infusion, the early promotion of a diuresis, and mild vasodilators to improve perfusion, many patients exhibit only minimal or transient impairment of renal function. MIEM has reduced its overall incidence of significant acute renal failure to 40 instances in the last 751 patients admitted. When established, however, the prognosis is poor despite full supportive therapy.[5]

4.3 New approaches in diuretic therapy,[9] facilitating the management of uncomplicated cases, have paralleled more aggressive and successful resuscitation and better support of the critically ill patient. These measures have resulted in a longer, more complicated survival for patients who would not previously have lived long enough to develop the present-day triad of renal failure, sepsis, and hepatic failure.

4.4 Uremia reduces the body's ability to deal with infection,[10] and many patients will die directly from sepsis. Montgomery *et al.*[4] estimated that 22% of postsurgical or trauma patients with acute tubular necrosis (ATN) died as a result of infection. Although the dangers of acute renal failure after trauma have been emphasized by pre-eminent authorities such as Black[11] and de Wardener,[12] the notoriety does not seem to have resulted in earlier aggressive therapy. Lordon and Burton[13] reported a 40% mortality with ATN following isolated face, head, or extremity injuries in contrast to an 80% mortality rate when the ATN resulted from trauma to the lower genitourinary tract, crush injuries, thoracoabdominal injuries, brain injuries, and abdominal injuries. While intense diuretic therapy may prevent or minimize the period of anuria, there is frequently such a high catabolic rate present in the trauma victim that hemodialysis may be indicated despite a high urine output.

4.5 Although the results of early hemodialysis in this context have yet to be scientifically assessed, there are reports which suggest it may be of value in battle casualties.[14,15] Other workers[6, 16-18] have demonstrated a reduced incidence of sepsis in patients receiving early dialysis, and Teschan[19] observed a decrease in incidence of drowsiness and coma and an improvement in wound healing. Fergus[20] reported a lower incidence of severe infections with earlier hemodialysis, and Lunding *et al.*[21] and Parsons[17] have all emphasized the role of dialysis in the prevention and treatment of the infective complications of acute renal failure. Kiley *et al.*[22] noted that dialysis proved to be more effective in preventing clinical deterioration than in restoring the patient after deterioration had occurred. Clinical observation at MIEM indicates that disturbances of conscious level commence in major trauma patients once the BUN level rises beyond 50 mg % and can be reversed by dialysis.

4.6 The results indicate survival is unlikely when a patient's renal function deteriorates to a defined level. Aggressive therapy must, therefore, be directed at preventing deterioration to this level.[23] A trial of early dialysis is necessary to assess the therapeutic effect of preventing the BUN from reaching 80 mg % and the serum creatinine level from reaching 4 mg %. This will frequently mean the implementation of dialysis within 24 hours of the trauma or surgery because of the gross catabolism and hyperkalemia. Peritoneal dialysis is unsatisfactory in these patients, who have, in many cases, recently undergone laparotomy; it results in excessively complex fluid management[24,25] and poor control over the hemodynamic state and interstitial fluid accumulation. In major trauma and septicemia, we have found transperitoneal exchange too slow to cope with the massive hypercatabolism in process. Most reported series reserve its use for less critical patients.[5,25]

4.7 We have previously reported the use of an Euclidean distance as a prognostic index[26] and that by combining commonly measured clinical parameters in this manner a downward trend can be identified several days before it becomes clinically recognized. Organ-orientated indices, based on calculated deviations from normal organ function, have considerable potential in the intensive care unit where over 100 biochemical and physiological variables are correlated daily by the physician. The renal index described here offers one such method of assessing patient deterioration and response to therapy. The application of an individual patient's parameters as shown in table A-8 would permit earlier planned hemodialysis, if necessary, within the first 24 hours of injury. A shunt could be inserted during the original operation and dialysis could proceed when indicated by the renal index.

4.8 Treatment of the multiple trauma victim is improving with rapid transport, specialized centers,[27] systematized resuscitation and diagnostic techniques,* effective transfusion policies, and adequate reoperation when necessary.**,[2] Early hemodialysis at present offers our only hope of reducing the mortality associated with acute tubular necrosis. Posttraumatic hemorrhagic diatheses have been virtually eliminated by the application of our active blood component (ABC) therapy† during the resuscitation phase. Bleeding disorders are frequently given as the contraindication for early dialysis. This is no longer acceptable as a valid reason for delaying early hemodialysis and, in those cases where we have pursued hemodialysis despite body areas which were oozing, few hemorrhagic problems have been encountered. It remains to be seen if the overall mortality rate will be reduced.

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APPENDIX

TABLES

TABLE A-1. RENAL FAILURE AFTER SURGERY

Investigator	Year	Cases	Mortality %
Swann and Merrill[28]	1953	39	67
Teschan *et al.*[14]	1955	51	53
Bluemle *et al.*[1]	1959	38	74
Parsons and McCracken[29]	1959	25	72
Slackman *et al.*[30]	1960	79	81
Kiley *et al.*[22]	1960	57	65
Alwall[31]	1963	371	63
Balslov and Jorgensen[7]	1963	184	64
Kennedy *et al.*[32]	1963	24	46
Lunding *et al.*[21]	1964	124	52
Marshall and Yoffa[33]	1965	57	40
Derot *et al.*[3]	1966	79	75
Kornhall[2]	1968	298	71
Berne and Barbour[34]	1971	18	67
Marshall[35]	1971	118	50
Stott *et al.*[5]	1972	37	70
Kennedy *et al.*[25]	1973	133*	58

*Surgical "conditions" not all postoperative.

TABLE A-2. RELATION OF URINE VOL_N TO URINE VOLUME PRODUCED BY PATIENT

Average urine volume per hour over 12 hr	Urine vol_N
ml	
>50	0
31-50	1
21-30	2
16-20	3
11-15	4
0-10	5

TABLE A-3. VALUES OF SERUM CREATININE, BUN, URINE VOL_N, AND RENAL INDEX RELATED TO SURVIVAL (N_L) OR DEATH (N_D) OF PATIENTS STUDIED

Creatinine			BUN			Urine vol_N			Renal index		
Value	N_L	N_D	Value	N_L	N_D	Value	N_L	N_D	Value	N_L	N_D
<1.7	538	82	<40	550	91	0	207	60	<2	558	97
1.7–4.0	40	40	40–80	36	26	1	159	14	2–3	14	11
>4.0	3	35	>80	4	40	2	118	13	>3	4	47
						3–4	95	24			
						5	7	44			

TABLE A-4. PROBABILITIES OF SURVIVAL (P_S) RELATED TO PARAMETERS MEASURED AND RENAL INDEX

Creatinine		BUN		Urine vol		Renal index	
Value	P_S	Value	P_S	Value	P_S	Value	P_S
0–1.7	0.87	0–40	0.86	0–2	0.85	0–2	0.85
1.7–4.0	0.50	40–80	0.54	3–4	0.80	2–3	0.38
>4.0	0.08	>80	0.09	5	0.14	>3	0.08

TABLE A-5. NUMBER OF TIMES EACH PARAMETER REACHED CRITICAL LEVEL FIRST AND NUMBER OF TIMES EACH PARAMETER REACHED CRITICAL LEVEL FIRST BUT SIMULTANEOUSLY WITH ONE OR MORE OF THE OTHER PARAMETERS IN THE COURSE OF PATIENT'S ILLNESS

	Creatinine	BUN	Urine vol	Renal index
First	1	8	4	15
First simultaneously with other parameters	11	13	6	18

TABLE A-6. RELATIONSHIP BETWEEN RENAL INDEX AND SURVIVAL OR DEATH

Renal index	Survived		Died	
	No.	Frequency	No.	Frequency
0–2	558	0.96	97	0.63
2-3	14	0.024	11	0.071
3–4	0	0	9	0.058
4–5	3	0.005	3	0.019
5–6	2	0.003	6	0.039
>6	5	0.009	29	0.187

TABLE A-7. MORTALITY OF PATIENTS WITH RENAL FAILURE FOLLOWING TRAUMA

Investigator	Year	Cases	Mortality %
Whelton and Donadio[15]	1969	18	67
Flynn[36]	1970	63	46
Berne and Barbour[34]	1971	8	75
Marshall[35]	1971	34	38
Lordon and Burton[13]	1972	67	63
Kennedy *et al.*[25]	1973	32	50

TABLE A-8. METHOD OF CALCULATING THE RENAL INDEX FROM URINE VOLUME, BUN, AND CREATININE

Urine vol (12 hr avg)/A		BUN (mg/100 ml)/B		Creatinine (mg/100 ml)/C	
>50	0	3	1	0.42	1
31-50	1	8	0.5	0.65	0.5
21-30	2	14	0	0.89	0
16-20	3	19	0.5	1.12	0.5
11-15	4	25	1	1.36	1
0-10	5	30	1.5	1.69	1.5
		36	2	1.83	2
		41	2.5	2.06	2.5
		47	3	2.30	3
		52	3.5	2.53	3.5
		58	4	2.77	4
		63	4.5	3.00	4.5
		69	5	3.24	5
		74	5.5	3.47	5.5
		80	6	3.71	6
		91	7	4.18	7
		102	8	4.65	8
		113	9	5.12	9
		124	10	5.59	10
		135	11	6.06	11
		146	12	6.53	12

Renal index = 1/3 (A+B+C)